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PHASE I REPORT

HYDRAULIC MODEL STUDY OF FLOW CONTROL STRUCTURES

Prepared for

USDA FOREST SERVICE

ANGELES NATIONAL FOREST

Pasadena, California

and

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Flagstaff, Arizona

Prepared by

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Engineering Research Center
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Fort Collins, Colorado

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November, 1977

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Angeles Flume Study

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GLOSSARY

aggradation--deposition in or filling of a stream's channel with sediment

bulking factor--ratio of the sediment volume or rate with voids in the clear water discharge volume or rate

catenary cable dam--a porous debris dam constructed of wire netting to temporarily trap sediment while allowing water to flow through

debris--rock, soil and vegetative material transported during flood flows

degradation--erosion of a stream's channel

ephemeral stream--a stream channel which does not contain flowing surface water most of the year

equilibrium--the state in a channel reach where erosion and deposition occur at equal rates thus not producing overall changes in the gradient of that channel reach

loading (filling)--deposition of debris behind a flow control structure

mathematical model--a model where processes in the system being studied are represented by mathematical formula

model--a representation of a planned or existing object

physical model--a scale model of a structure or a stream reach

prototype--a planned object that is to be built or modeled

sediment---inorganic rock or soil material transported by water

sediment debris--inorganic rock and soil material transported during flood flows

self-cleaning--design of a flow control structure that permits low flow erosion of a sizable portion of deposited debris

split dam--a water and sediment detention dam that is separated in two halves by a center vertical cut of varying shape

top-tie pile wall dam--a solid dam composed of vertical H-beams with timbers that slide into the grooves in the beams, with cable placed between the dam's crest and upstream anchors to prevent overturning of the dam

transport capacity--maximum rate at which a stream can carry sediment above which deposition occurs

unloading (scouring)--erosion of material through the port of a flow control structure by water flow

vegetative or organic debris--organic material, such as trees and brush, transported during flood flows

PREFACE

This model study was conducted for the Angeles National Forest, Pasadena, California through Research Agreement No. 16-712-03-CA between USDA Forest Service, Rocky Mountain Forest and Range Experiment Station and Colorado State University. Ron S. Aygarn is the authorized project coordinator and D. Ross Carder is the authorized project officer for the USDA Forest Service. Daryl B. Simons and Ruh-Ming Li are the principle investigators at Colorado State University. The project was divided into two phases. The period of agreement for Phase I study is from August 25, 1977 to September 30, 1977. According to the study plan, Phase I report on the experimental designs, initial findings and recommendations for the scope of work of Phase II is submitted.

Problems of sedimentation and structures for controlling it have attracted the attention of scientists and engineers throughout the world in recent decades. Millions of dollars have been spent to collect laboratory and field data to quantify the transport rate, erosional and depositional characteristics and performance of hydraulic structures. The increasing needs to manage rivers and watersheds has led to increased use of convenient and less costly laboratory flumes for developing timely specific information. Most previous studies have been concentrated toward solving sediment problems in relatively flat gradient channels. Very few studies have been conducted that simulate steep mountain channels. Knowledge of watershed management and system response in steep mountain channels is urgently needed.

This model study is the first attempt at Colorado State University, possibly the first major attempt in the world, to study the hydraulics, sediment transport and response of hydraulic structures in steep

mountain channels. Because a tremendous amount of sediment must be fed and/or cleaned out of the model, many staff members, graduate students and undergraduate students were involved in assisting the writers with these difficult experiments. The writers wish to acknowledge Dr. J. Bathurst, Mr. K. Eggert, Mr. L. Shiao, Mr. C. Orvis, Mr. G. Brown, Mr. M. Stay, Ms. Carla Worley and Mr. D. Hartley for their excellent assistance and great patience in working overtime and long hours. Mr. Ewald Patzer, machine shop foreman, and his excellent crew helped a great deal in designing and fabricating the experimental facility. Without their assistance, this study would not be possible. Special thanks are due to Robert Stearly for photographing the experimental runs. Finally, the writers are indebted to Mr. Ron Aygarn and Mr. David McCauley of the Forest Service for their guidance and constructive suggestions.

EXECUTIVE SUMMARY

Angeles National Forest personnel, Pasadena, California are currently investigating efficiency of the split dam prototype structures and catenary cable dams to control water and sediment flows in mountain channels of the San Gabriel Mountains, Southern California. The overall purpose of such structures is to reduce the peak of water and sediment flows during heavy storms, and eventually pass most of the stored sediment through the system during periods of smaller flows. A hydraulic model study of these structures is being conducted at Colorado State University.

The primary objective of this model study is to identify the efficiencies of the two selected flow control structures (catenary cable and split dams) in altering normal sediment movement through steep ephermal channels below highly erodible watersheds. The other objective of this study is to establish recommendations regarding design modifications that will improve functioning of the selected structures.

The study was divided into two phases. This Phase I report documents the design of experimental facilities and models, the initial findings, the results of flume runs and recommendation for the Phase II study. In the Phase I study, a total of 57 flume runs were completed. In the recommended Phase II study, approximately 110 additional runs plus development of mathematical models capable of predicting the hydraulic response of a proposed structure for different structural and hydraulic conditions will be conducted.

Results of the Phase I study suggest that the split dam prototype with the desired self-cleaning capability performs very well. However, the efficiency of the self-cleaning feature is dependent on the shape of the structure's opening, the rate and duration of low flows and corresponding sediment

loads, the channel slope, and the sediment size and size distribution. In the recommended Phase II study, the efficiency of the self-cleaning feature of a proposed structure will be determined utilizing both physical and mathematical models.

I. INTRODUCTION

The Angeles National Forest, Pasadena, California, through the Rocky Mountain Forest and Range Experiment Station requested with the Engineering Research Center, Colorado State University to investigate the efficiency of the proposed prototype split dam structure and catenary cable dam to control water and sediment debris flows in mountain channels of the San Gabriel Mountains, Southern California. The overall purpose of the proposed structure is to reduce the peak of water and sediment through the system during periods of small flows. A hydraulic model study of these structures is being conducted at Colorado State University.

The first objective of this physical model study is to identify the relative efficiencies of the two selected flow control structures (catenary cable and split dam) to favorably alter the normal sediment movement through steep ephemeral channels that drain highly erodible watersheds. The second objective of this study is to establish recommendations regarding design modifications that would improve the functioning of the selected structures.

Proposed structures to be studied were designed to adjust sediment transport during rare runoff events. When functioning ideally, these structures will (1) pass all of the water and rock debris during runoff events that are less than a stipulated rare runoff event, (2) partially impound water and rock debris during the stipulated rare runoff event, and (3) pass impounded rock debris during subsequent runoff events that are less than the stipulated rare runoff event. To accomplish the two objectives, structure modeling and flume runs were performed to determine the hydraulic response of the natural channel system to the design of cross-channel structures. Hydraulic response of the natural channel

system required determination of water velocity, depth, discharge, sediment transport, sediment size, degradation and deposition. Design of each structure involves the size of the structure, its shape, the openings, channel shape and channel slope. General questions pertinent to the proposed structures were: (1) changes in energy concentration, (2) changes in water and rock debris storage and flow, (3) rock debris deposition and transport, and (4) the most effective shape of structures for efficient self-cleaning.

On October 11-12, 1977, Mr. Ron Aygarn and Mr. David McCauley of the Forest Service visited Colorado State University and observed preliminary flume runs using models under examination. The catenary cable model was proven to be inefficient in self-cleaning and was excluded from further analysis by the Forest Service. The study was then revised. The revised study requirements were as follows: Two split dam configurations were examined. One model contained a scaled down opening representing a 5'-0" wide x 7'-0" high vertical hole below a 3-foot wide vertical outflow port. This is called the Ogee model because it incorporated the double conical transition from the larger to the small opening. The second split dam model contained a scaled down dimension representing a 4'-0" high x 8'-0" wide horizontal hole below a 3-foot wide vertical outflow port. This is called the rectangular model. In Phase II of this study the solid top-tie pile wall will be examined as necessary to develop sediment routing data for comparison with the split dam models. Three channel slopes, 5 percent, 15 percent and 25 percent, will be used in this study. The basic flume runs required are classified into the following three groups: (1) Group I--determine clear water discharge rate for two split dam shapes, each on

three slopes with various model flow depths, (2) Group II--determine the maximum natural sediment transport rates for various water discharges in open channel flow without models, (3) Group III--determine sediment loading and unloading rates of the two split dam shapes. The Phase I study included the flume runs of Groups I and II and included flume runs of Group III for one structure shape and one slope. Only one sediment and vegetative debris distribution was used in the Phase I study.

II. FACILITY AND MODEL DESIGN

2.1 General Layout

To conduct the experiments required innovation. In order to simulate the field situation, a unique flume capable of a large range of slopes was constructed. The outstanding feature of the flume is that it is pivoted at the downstream end and attached to a stationary forklift at the upstream end. Slopes from zero up to about 30 percent are possible. The general layout is shown in Figure 1 and Plate 1. Besides the pivot and lift system for achieving high slopes, the flume layout includes:

(1) A flexible water supply hose system that allows the flume to be raised and lowered,

(2) A sediment settling tank (at downstream end of flume in Plate 1),

(3) A belt conveyor with a calibrated variable speed feeder hopper (Plate 2),

(4) A calibrated weir with stilling basin measurement gage (Plate 3),

(5) A six, 650-watt bulb lighting system for photograph,

(6) Artificial gravel roughness cemented to the bed (Plate 4),

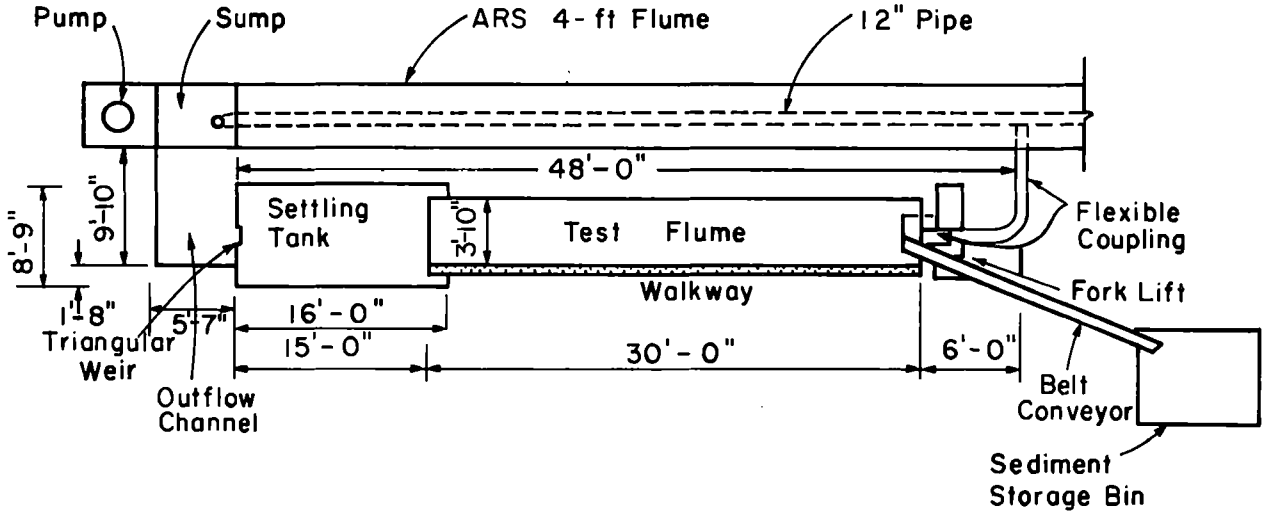
(7) Model structures (Plate 4), and

(8) Instrument carriage for measuring the bed profile.

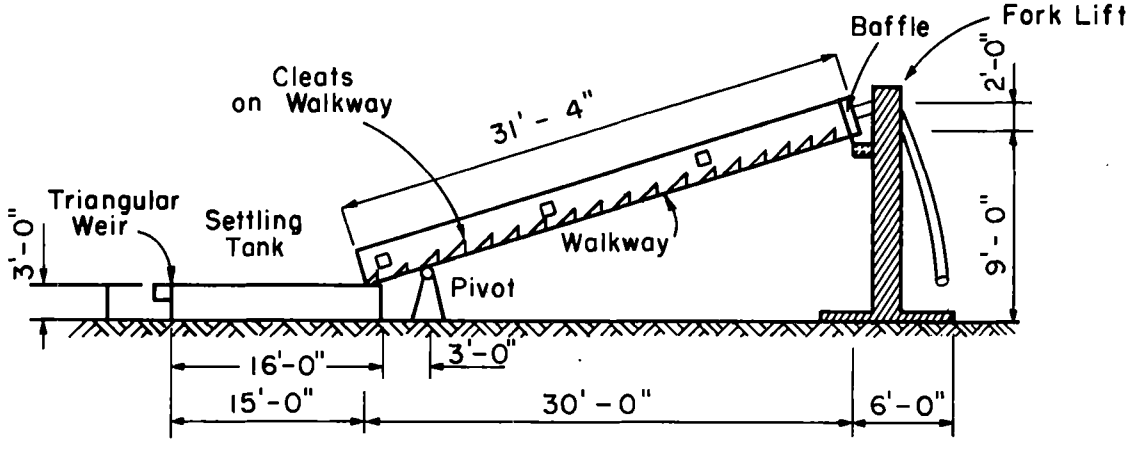
An overall upstream view of the facility showing weir, stilling basin, flume and structure is shown in Plate 5.

2.2 Calibration and Adjustment of the Facility

Three items required calibration or adjustment before flume runs could be made. First, the flume was raised to the prescribed



Top View



Elevation

Figure 1. Sketch of the test flume layout (not to scale).

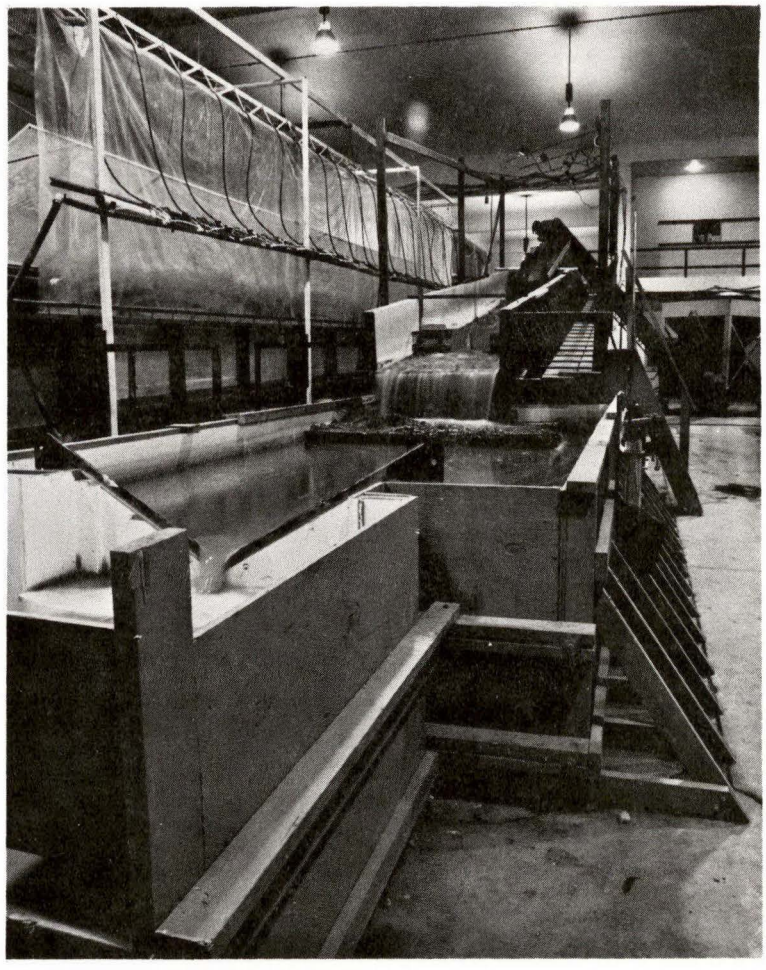


Plate 1. General layout of experimental flume facility.

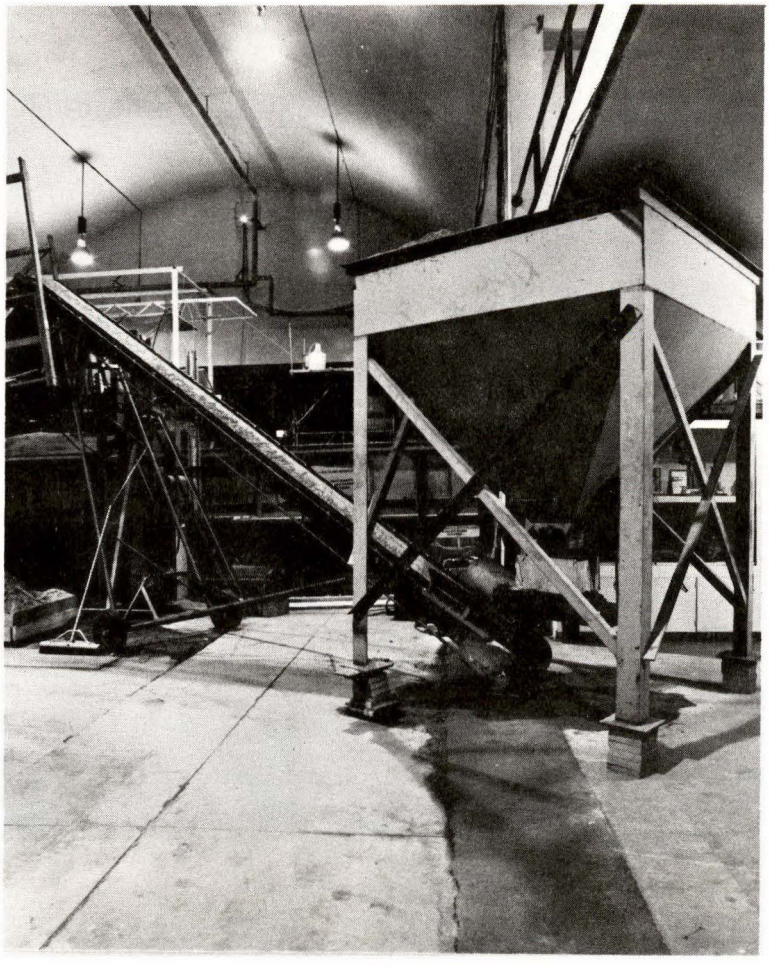


Plate 2. Belt conveyor sediment feed system with sediment hopper.

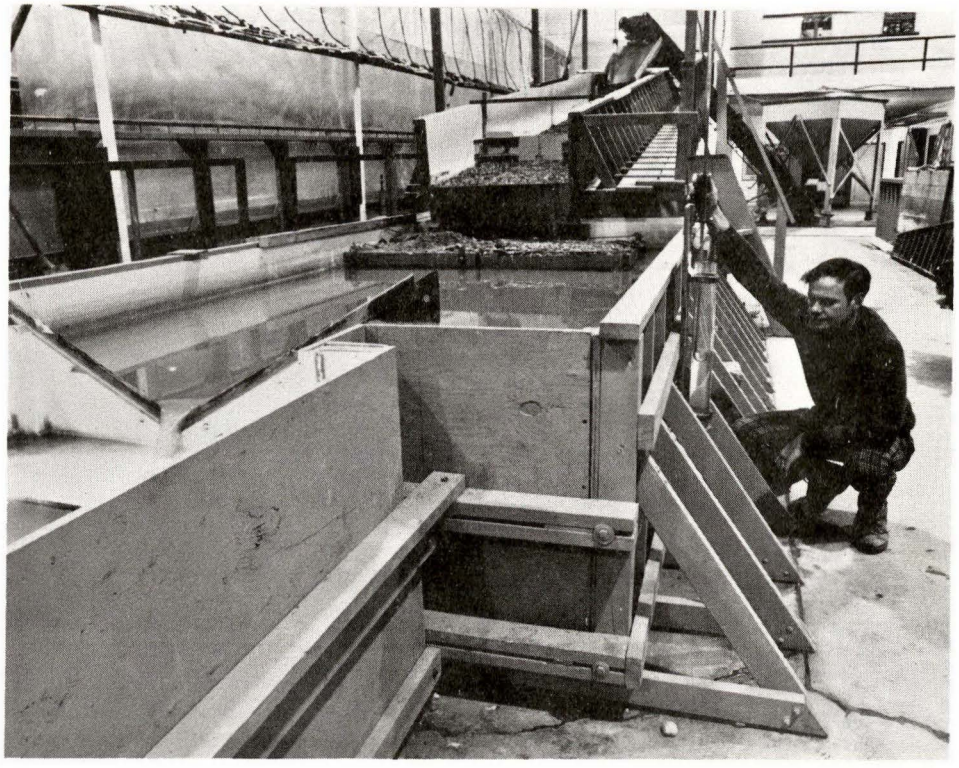


Plate 3. Calibrated weir on settling tank with stilling basin for water surface elevation measurements.

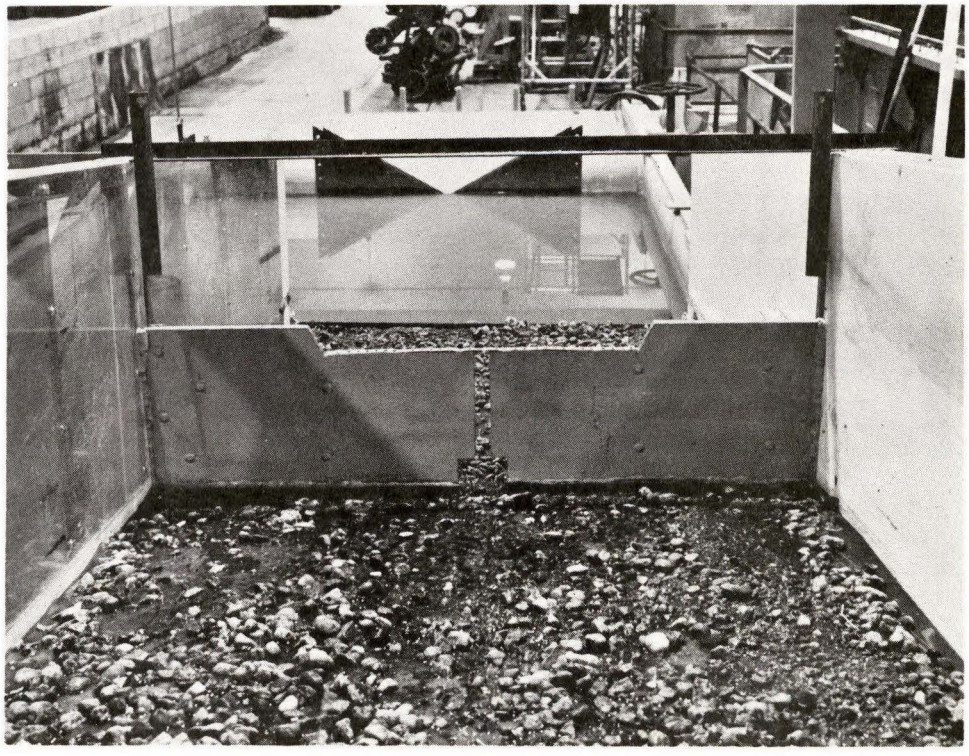


Plate 4. Artificial gravel roughness and model structure.

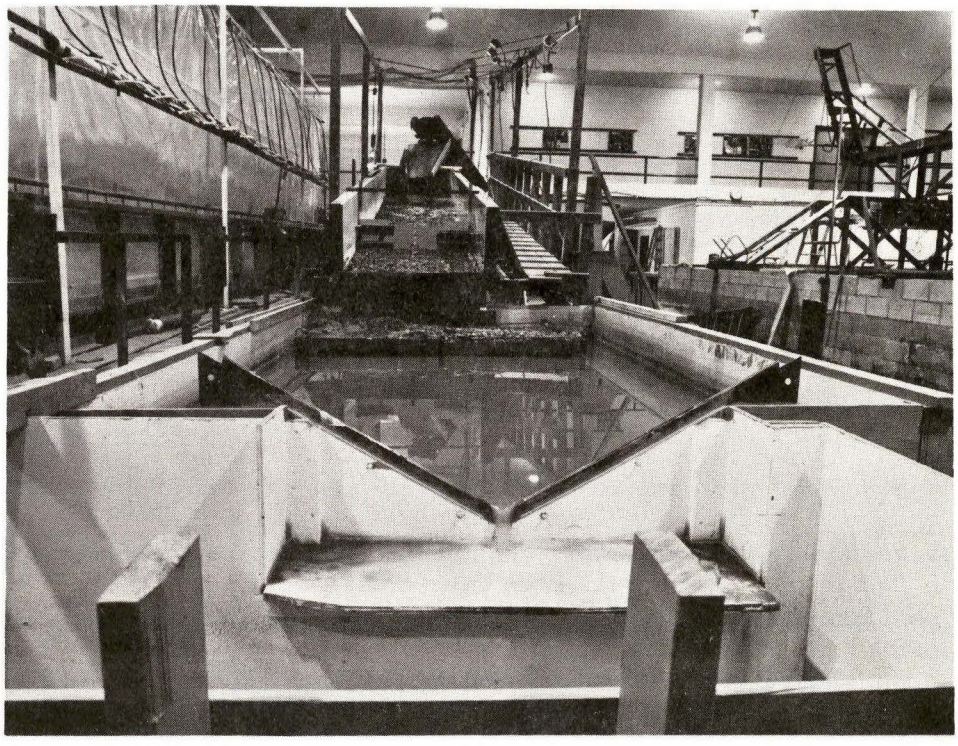


Plate 5. Overall view of flume facility looking directly upstream along flume axis.

slope and leveled cross channel. Braces were then used to support the flume at each slope. Second, the weir was installed and the stilling basin gage was surveyed in order to give direct readings of head over the weir (Plate 3). The weir was previously calibrated. The weir was then used to find approximate control valve positions for selected water inflow rates. Third, the sediment feed rate from the hopper was calibrated at different motor speeds and hopper throat openings. The sediment feed rate was calibrated by noting the length of time necessary to discharge a measured volume of sediment. These calibrations and adjustments allowed the measurement of both water and sediment inflow rates and channel slopes.

2.3 Model Scale

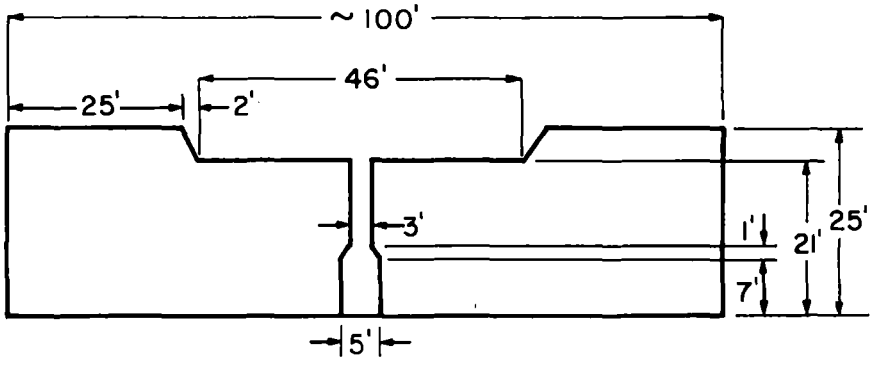
The purpose of a scale model is to simulate the prototype or field situation as close as practical. Numerous model scales can be devised depending on the conditions of the system being modeled. In this study, Froude number similarity was used. The Froude number is the dimensionless ratio of gravity force to inertia force, often defined as water flow velocity divided by the square root of water depth times the gravitational acceleration, i.e., 32.2 feet per second at sea level. Froude number similarity coupled with the length scaling factor used in the model permitted determination of the necessary length, volume, velocity and time in the model. In Phase I the following dimensions were used with a 1/25-length scale.

Table 1. Scaling of the model.

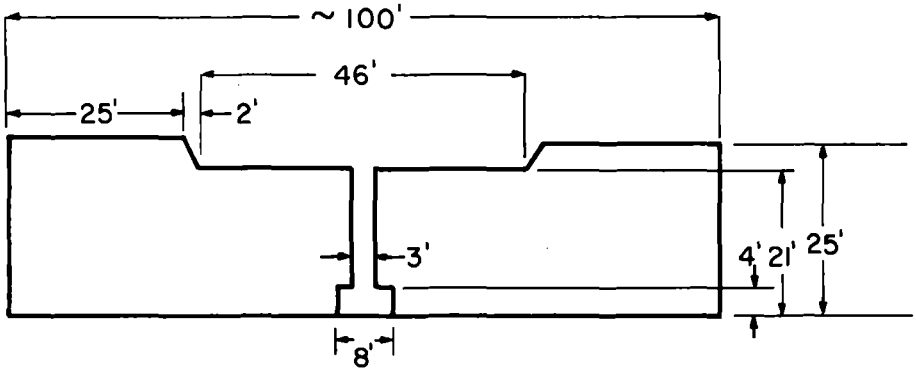
Prototype	Model
1 foot	1/25 = .04 feet = 0.48 inch
1 cfs	$1/(25)^{5/2}$ = 0.00032 cfs
1 hour	$1/(25)^{1/2}$ = 0.20 hrs = 12 mins
1 Mannings n unit	$1/(25)^{1/6}$ = 0.58 unit

Using the model scaling factor the flume width of 46 inches represents a 96-foot wide channel and a 1.92 cfs flume discharge represents a flow of 6000 cfs in the prototype. The estimated Manning's n of 0.07 in the prototype was reduced and verified equal to 0.041 in the model (Plate 4). The verification was made by using Manning's equation with measurements of flow depths for certain discharges in the model. The dimensionless slopes of 5 percent, 15 percent and 25 percent remained constant.

The length scale was used to reduce the two prototype dams and the sediment dimensions to model sizes. Dimensions of the two prototype dams, Ogee and rectangular, are shown in Figure 2. These two structure shapes are shown in Plates 6 and 7.



Ogee Shape



Rectangular Shape

Figure 2. Sketches of prototype debris dams.

Plate 6. Ogee shape split dam model.

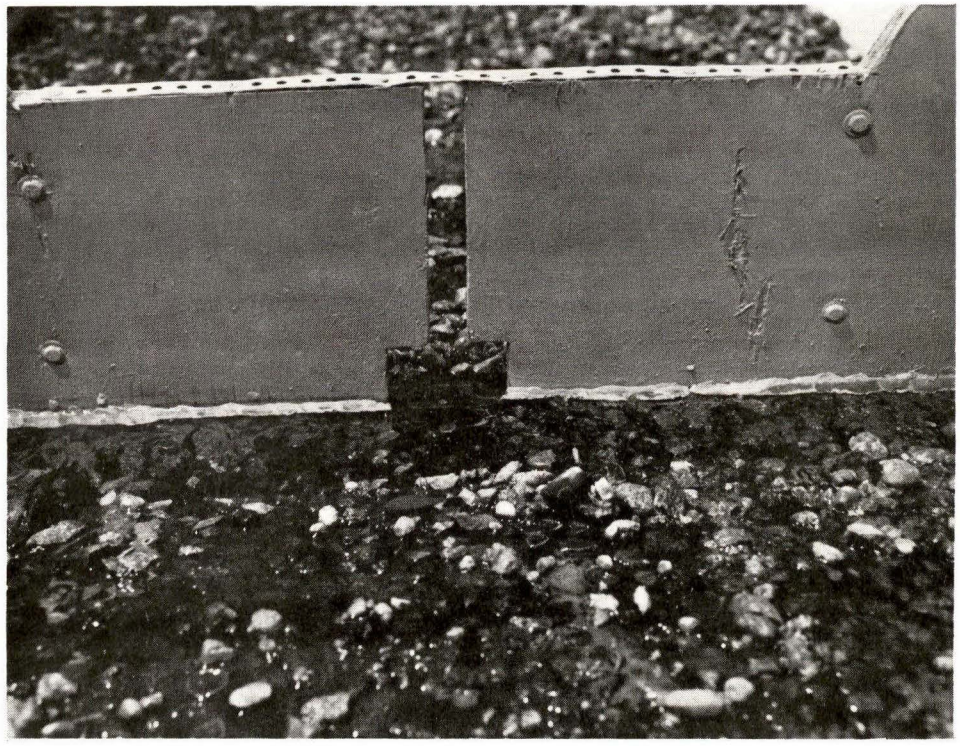


Plate 7. Rectangular shape split dam model.

III. PROCEDURES AND FINDINGS

Procedures for conducting the model study and the results of Phase I flume runs are summarized.

3.1 General Findings

The catenary cable model will not significantly retard water or a sediment debris flow that is composed of material ranging from clay to cobble unless holes in the cable network are quite small. When the holes are small, debris will readily plug the holes and induce deposition behind the structure. Self-cleaning is not possible with this model because subsequent water flow is not concentrated sufficiently to transport the debris through the holes. The catenary cable model traps the selected size of debris but does not have self-cleaning features. Further analysis of this model is excluded.

From the initial flume runs, it is concluded that the split-dam configuration has the desired self-cleaning features. However, efficiency of the self-cleaning feature is dependent on the shape of the structure's opening, the rate and duration of low flow and corresponding sediment loads, the channel slope, and sediment size and size distribution. Low flows with very little or no sediment load are able to remove a significant percent of the stored sediment because the bed slope on the downstream face of the prism of the stored sediment is much steeper than the channel bed slope. However, there are two potential problems involved if the low flow is small and of short duration. First, low flow may erode only a small gully through the sediment prism. Second, low flow may be entirely contained in the porous media as subsurface flow, thus, greatly reducing sediment erosive capacity. In addition, it was observed that the scour potential downstream of the split-dam port during high flows is

very large. A layer of heavy armor by an appropriate size of riprap is needed to preserve the integrity of the structure. Conversely, during low flows, the sediment discharged through the structure will form an alluvial fan below the structure due to the deposition of sediment. Most of this alluvial fan may be transported downstream by subsequent high flows, adding to the sediment load. If a series of the split dams are contemplated, an analysis of the erosional and depositional response of the whole system is needed to evaluate the self-cleaning efficiency.

3.2 Procedures and Findings, Group I Runs

This set of runs was conducted to determine the depth of water at the dam for various clear water discharges. Five water depths at three channel slopes for two dams were used. The depths, in prototype dimensions, were approximately 2', 8', 21', 25', and 27' above the channel bottom. After the dam was set in place, water was released down the flume. The discharge valve was adjusted until the depth became steady at or near a predetermined level. Discharge was then determined by reading the steady gage height in the stilling basin. Plates 8, 9 and 10 show upstream, downstream and side views of the Ogee dam at 15 percent slope and a prototype water depth of about 8'. Results for the two split dams are presented in Table 2. Discharges are given in the prototype values for an easier interpretation. For convenience results are plotted in Figures 3 and 4. These figures indicate that the two structures have a similar hydraulic performance. However, they may have different self-cleaning efficiencies. The difference in self-cleaning efficiencies for the two shapes is expected due to the difference in the energy concentration and ability to pass vegetative debris.

Plate 8. Discharge--water depth rating experiment view looking upstream of Ogee shape dam on 15% slope with 8-foot prototype depth.

Plate 9. Discharge--water depth rating experiment view looking downstream of Ogee shape dam on 15% slope with 8-foot prototype depth.

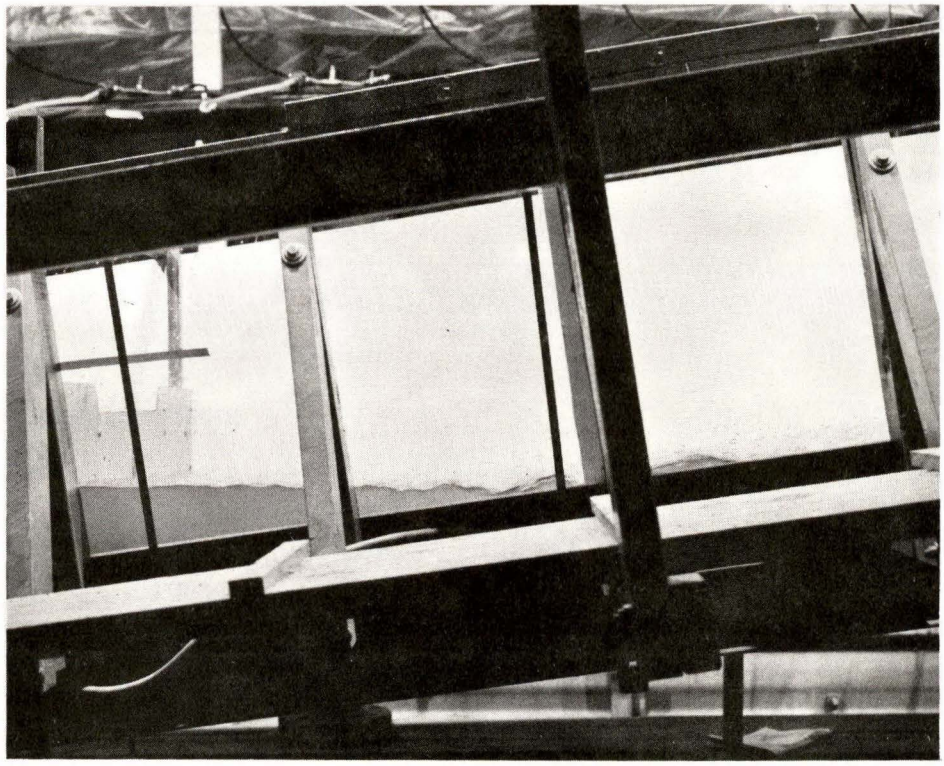


Plate 10. Discharge--water depth rating experiment side view of Ogee shape dam at 15% slope with 8-foot prototype depth.

Table 2. Group I runs--depth on dam and discharge (prototype values)

A--Ogee Shape

Slope					
5%		15%		25%	
Depth feet	Discharge cfs	Depth feet	Discharge cfs	Depth feet	Discharge cfs
2.2	55	4	144	5.5	173
4.7	181	11.7	662	8	371
8	420	21	1486	21	1441
21	1559	25	2739	25	2294
25	2951	27	5116	27	5268
27	5023				

B--Rectangular Shape

5%		15%		25%	
Depth feet	Discharge cfs	Depth feet	Discharge cfs	Depth feet	Discharge cfs
3.3	106	4.8	222	3.6	71
3.8	181	9.6	571	8.0	460
8.2	492	20.6	1388	20.7	1371
21	1432	25	2548	25	2318
25	2831	27	4641	27	4985
27	4784				

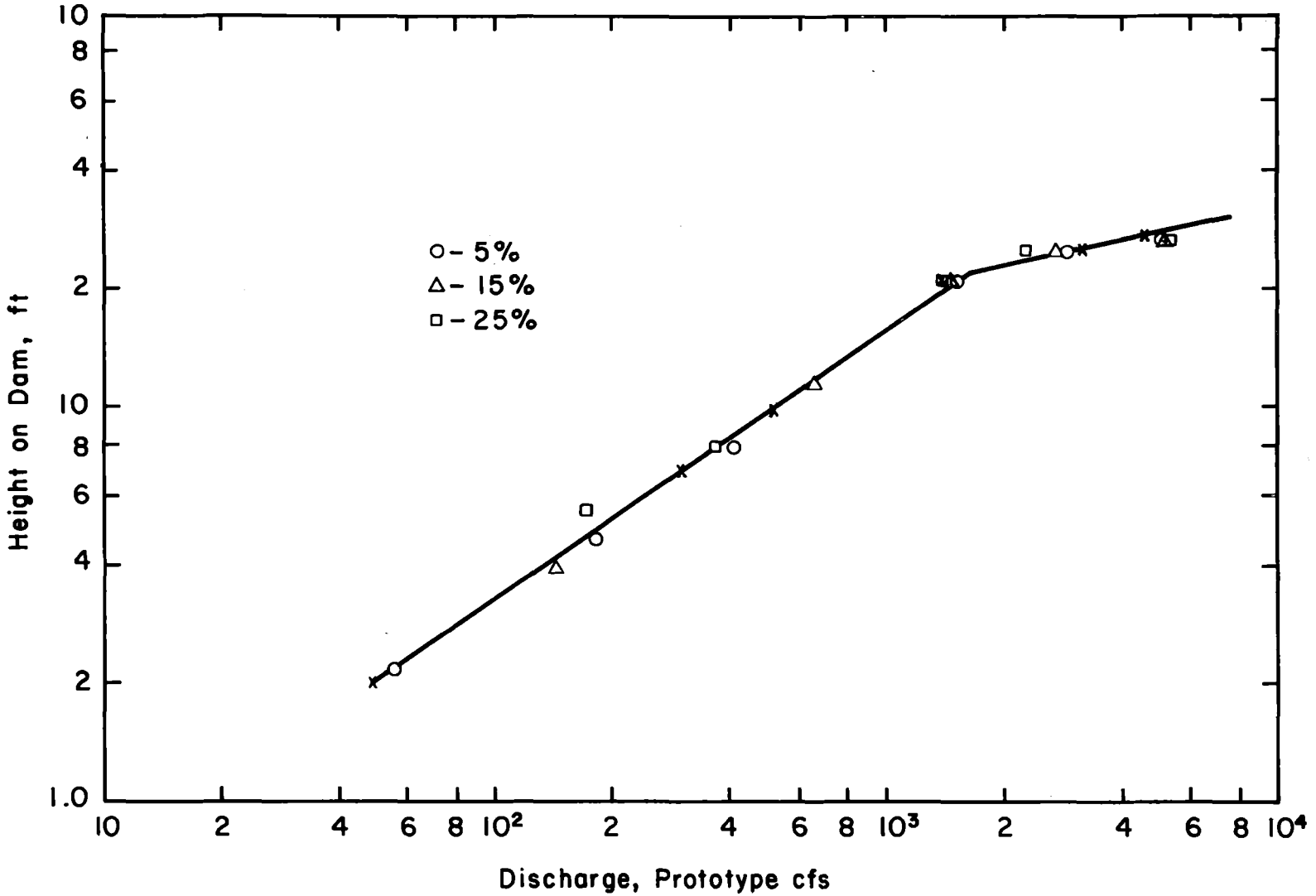


Figure 3. Angeles National Forest, debris dam study. Depth on dam vs. discharge for prototype dam, Ogee shape.

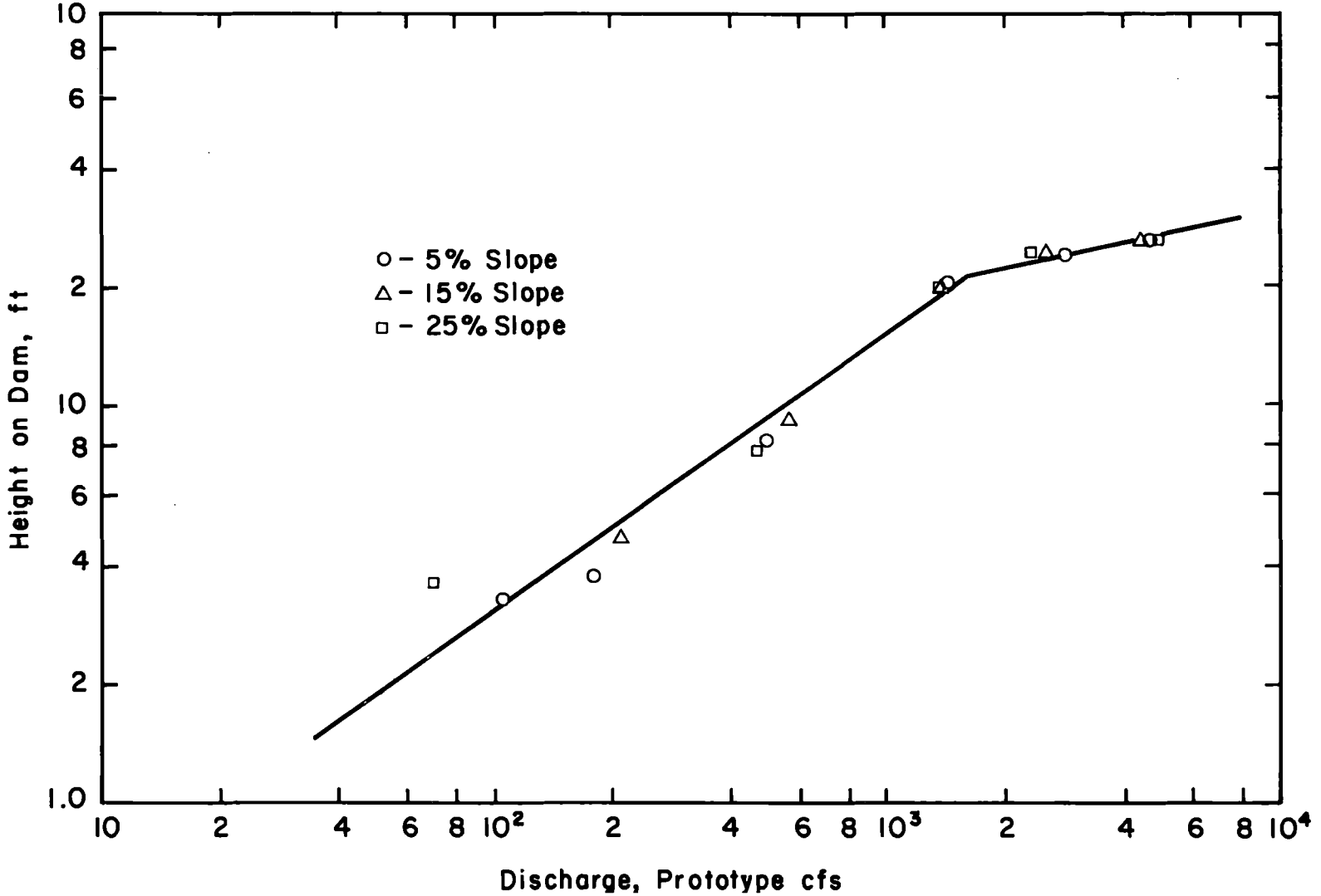


Figure 4. Angeles National Forest debris dam study. Depth on dam vs. discharge for prototype dam, rectangular shape.

3.3 Procedures and Findings, Group II Runs

This set of runs determined the channel's sediment transport capacity for various water flows and slopes. Volumetric sediment rates were measured for the various flow conditions. For discharges on the five percent slope, the sediment feeder could be adjusted to supply adequate sediment to avoid significant aggradation or degradation of the 3-inch hand-laid sediment bed, thereby maintaining an equilibrium condition. For 15 percent and 25 percent slopes, the rate at which sediment could be supplied was inadequate and a 6-inch bed was necessary to supply adequate sediment. In the 15 percent and 25 percent runs, the transport capacity was quickly reached allowing short run times. The bed on these steep slopes was checked constantly to assure that the sediment supply was adequate for the flow conditions.

The run was stopped before complete scour of the bed took place. Plates 11, 12, 13 and 14 show the channel before the run, looking upstream during the run, from the side during the run and after the run looking upstream. These photographs show that under these conditions the bed was in equilibrium with the flow.

During each run, volumetric sediment samples were collected as shown in Plates 15, 16, 17 and 18. Plate 15 shows the sediment collector in place catching a timed sample. Sediment was then leveled (Plate 16), measured (Plate 17), then dumped in preparation for the next sample (Plate 18). Samples of supply and outflow sediment were periodically collected for sieve analysis. The collected samples were converted to volumetric rates and checked to determine if a steady rate was achieved. The average representative rate was determined from a set of carefully measured samples. The water discharge

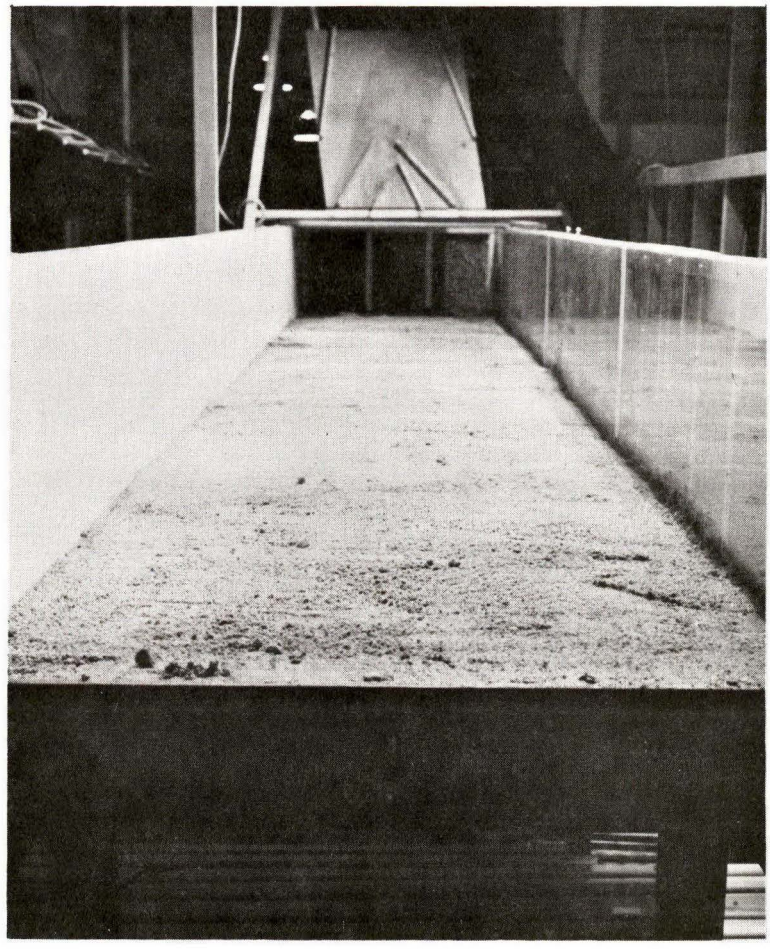


Plate 11. Sediment transport capacity experiment -- Pre-run channel surface.

Plate 12. Sediment transport capacity experiment -- upstream view during run.

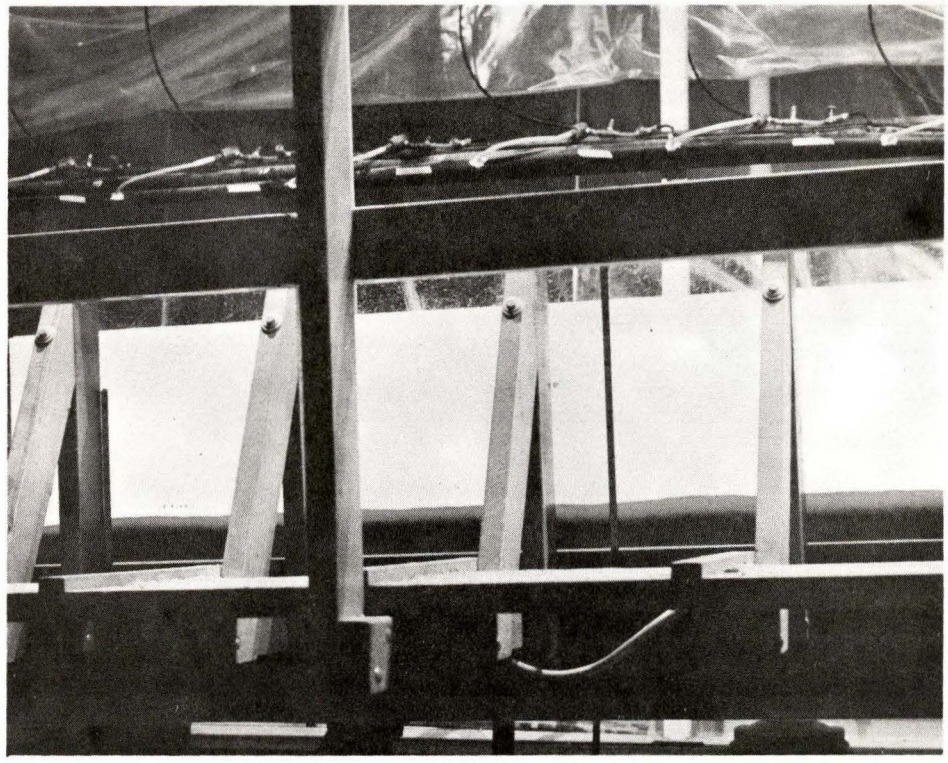


Plate 13. Sediment transport capacity experiment -- side view during run.

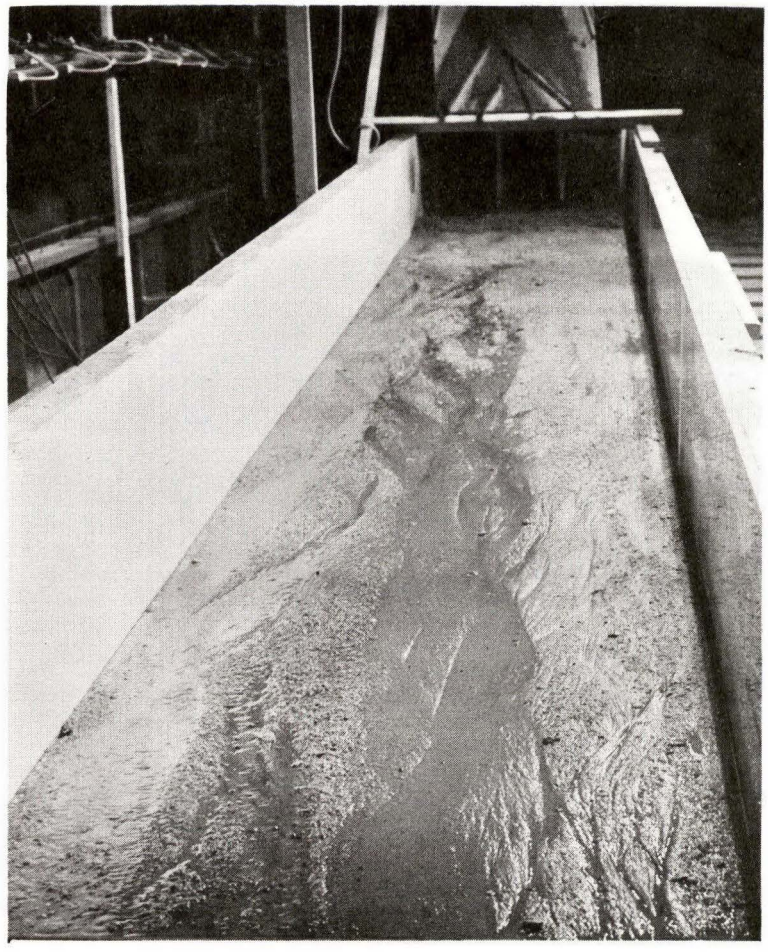


Plate 14. Sediment transport capacity experiment -- post run channel surface.

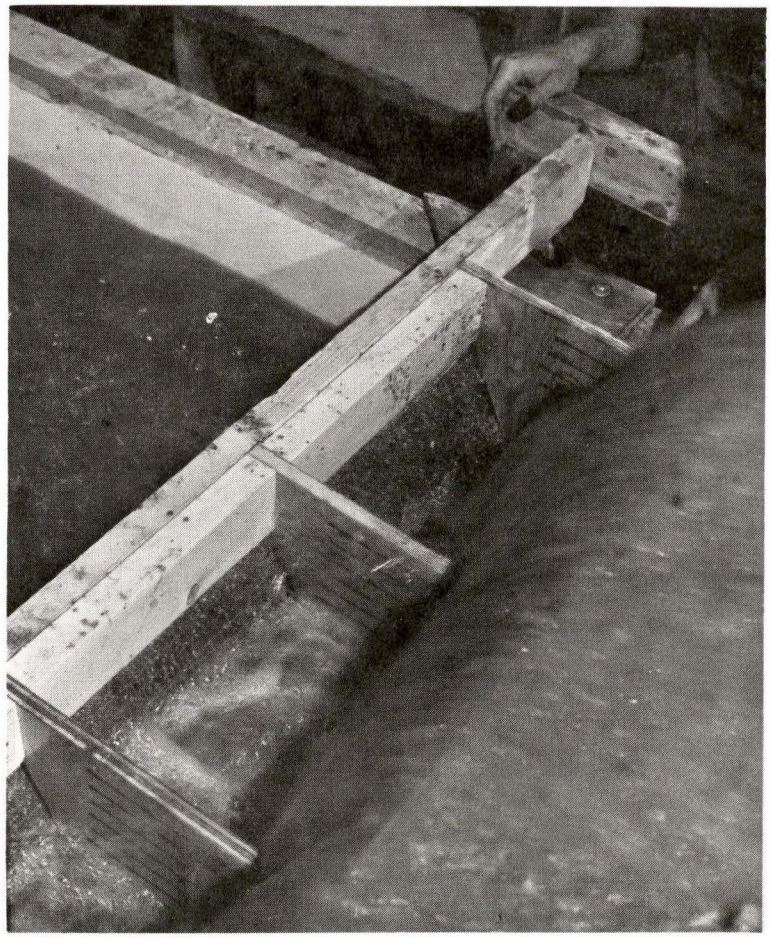


Plate 15. Sediment transport capacity experiment -- sediment sampler collecting sample.

Plate 16. Sediment transport capacity experiment -- levelling of sample before measurements.

Plate 17. Sediment transport capacity experiment -- measurement of sample.

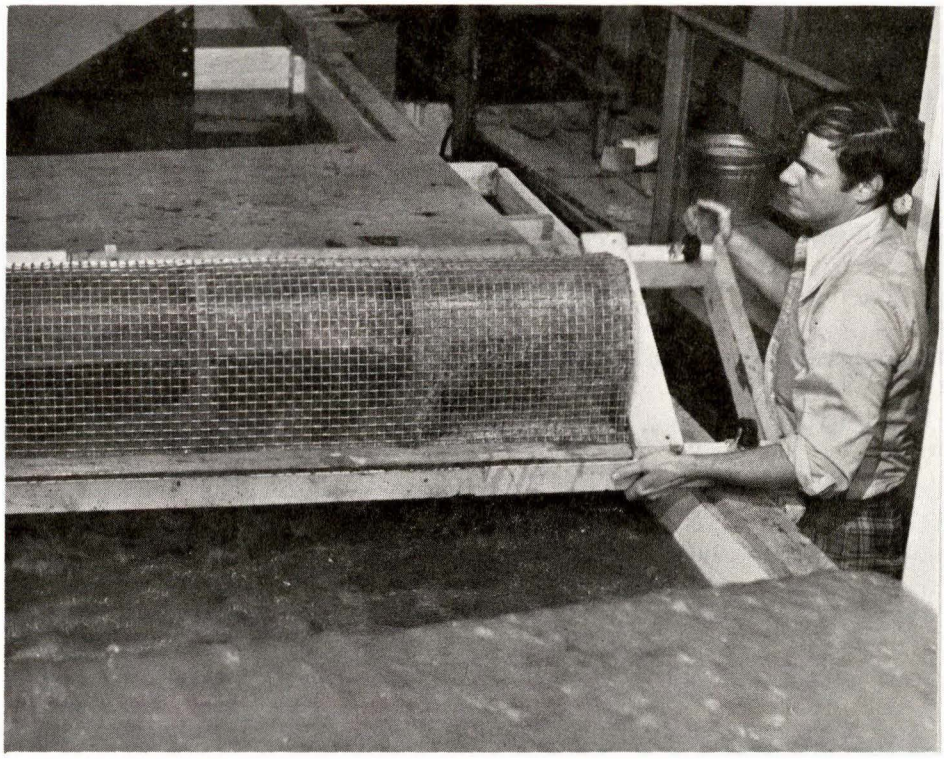


Plate 18. Sediment transport capacity experiment -- emptying of sampler before next sample.

was measured for the sediment discharge where necessary. Data from these runs consisted of water and sediment flow rates at the different slopes. Sieve analysis of the sediment supply and sediment outflows showed the fine sediments not caught in the sediment sampler represented about one percent of the total transport well within sampling error (see Figure 5). Therefore, corrections for minor amounts of fine materials not measured were not computed. The model sediment sizes represent debris sizes in the prototype ranging from very fine gravel to small boulders. Smaller sizes of prototype sediment cannot be efficiently modeled.

The "sediment transport capacities" are the "equilibrium channel sediment transport rates" for each respective water discharge, i.e., sediment supplied to the flow per unit time equals sediment passing out the bottom of the flume per unit time at a constant water discharge. The range of prototype water discharges studied was from 400 cfs to 5000 cfs. The 400 cfs prototype discharge was fixed as the limitations of the model facility. In these runs, vegetative debris was not added. The results of Group II flume runs are presented in Table 3 and Figure 6. Transport rates are expressed as the volume of porous sediment (with voids) per unit time. These values are the maximum sediment transport rates for the selected size distribution (see Figure 5) and bed slope. According to the data obtained, the maximum bulking factor is about 92 percent which is very similar to that determined by the Los Angeles County Flood Control District Hydrology Manual, December 1971. It is important to note the direct proportionality of the sediment discharge to the water discharge as determined by the flume runs is within reasonable agreement with the Meyer-Peter, Müller sediment transport equation.

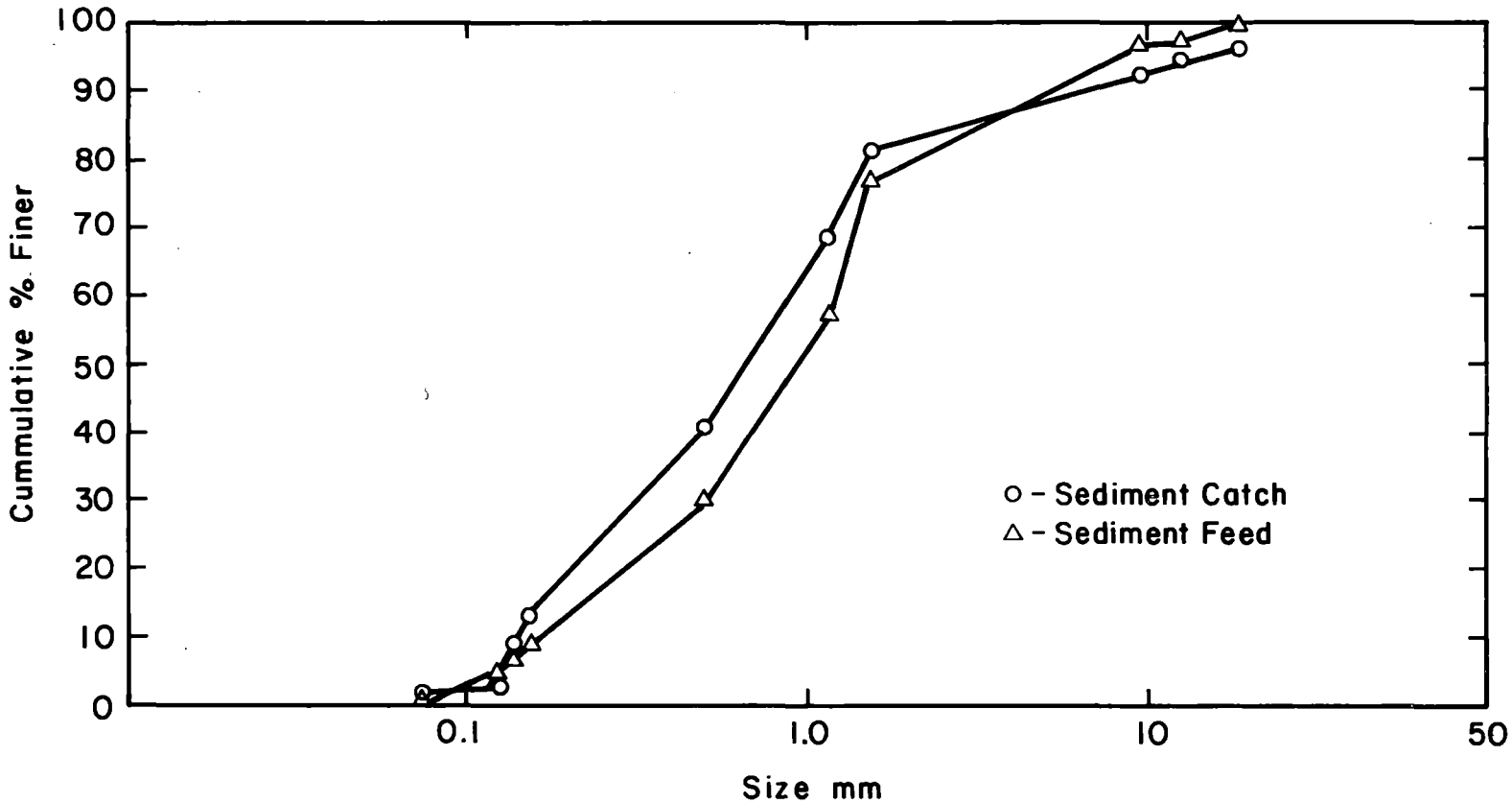


Figure 5. Model sediment size distribution.

Table 3. Group II runs--water discharge and sediment transport capacity (prototype values) for three slopes

5%		15%		25%	
Qw	Qs	Qw	Qs	Qw	Qs
1259	59	425	166	556	641
1969	88	1088	594	1406	1075
2584	103	1762	819	2281	1966
3300	125	2559	1256	2559	2290
4719	247	4447	1753	4125	4019

Qw is without sediment
Q is in cubic feet per second
Qs is the sediment flow rate, measured as porous volume (with voids)

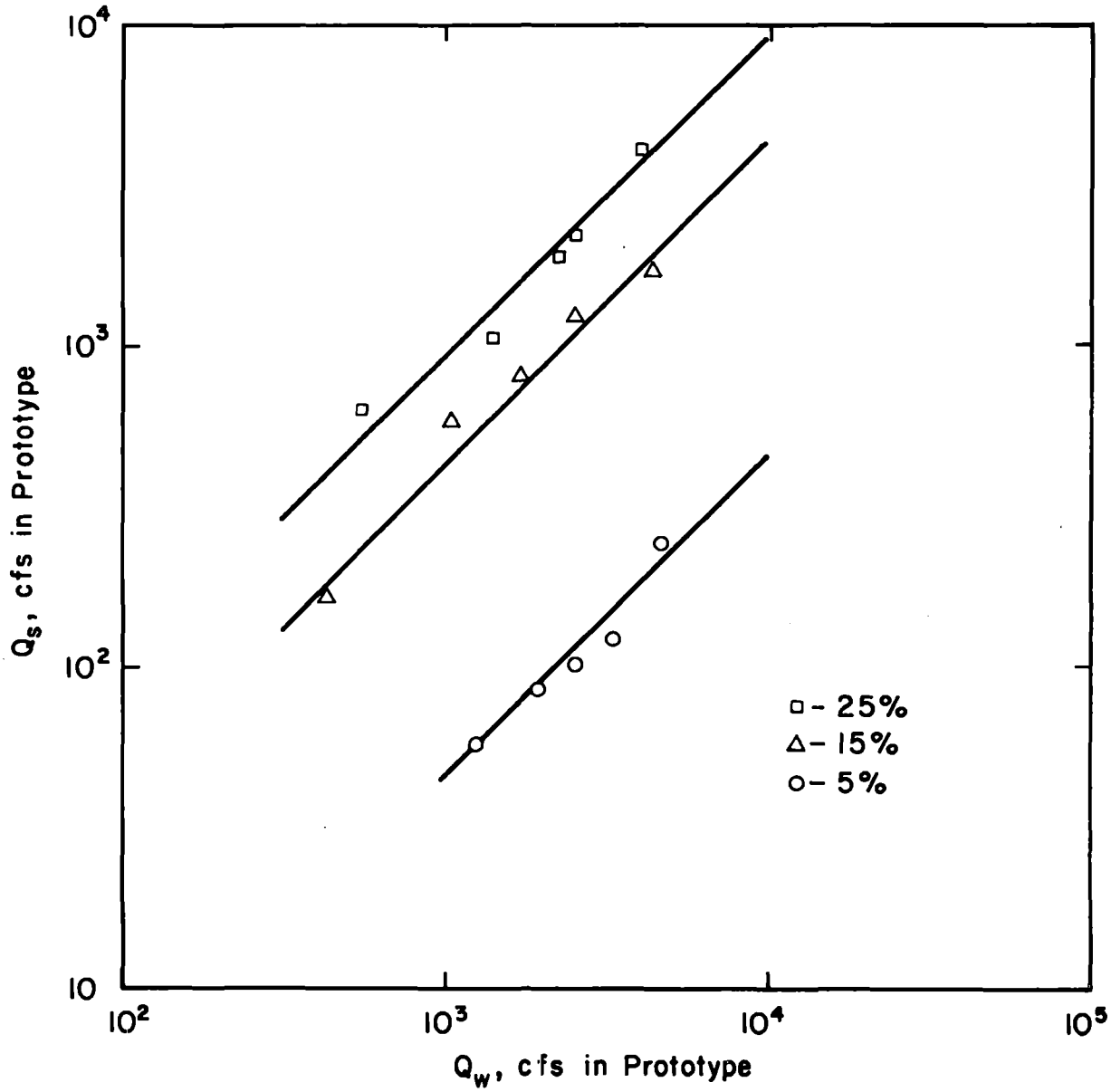


Figure 6. Sediment discharge vs. water discharge.

3.4 Procedures and Findings, Group III Runs

This group of runs determined the loading (filling) and unloading (scouring) rate of the sediment in the prism upstream of the model structure under different sediment and water discharges. In these runs a 6-inch bed of sediment was placed in the flume. The debris dam was placed on top of this bed attached to a 6-inch high cutoff wall. Water and corresponding equilibrium sediment discharges were run through the dam for the time required to fill the dam to the spillway level or until no significant change in the volume of deposited sediment was observed. The volume of deposited sediment was then profiled and computed. The bed was leveled at the dam and a clear water discharge was allowed to scour the sediment until approximately half of the volume of stored sediment was eroded or until changes were insignificant. Similar scouring runs were also conducted at one-half of the channel sediment transport capacity rate determined in Group II. Data from Group III runs consist of water discharge rates and rate of sediment filling or scouring. Sediment discharge samples were collected to check on loading and unloading rates. Plates 19, 20, 21 and 22 show the dam during filling (Plates 19 and 20), and after filling (Plates 21 and 22) with discharges to 1400 cfs (prototype). Note the scour hole downstream of rectangular dam opening in Plate 19. Similar photographs document the unloading of the structure in Plates 23, 24, 25 and 26. During these runs modeled vegetative debris was introduced in the form of wood shavings, shredded plastic, toothpicks and dowels. Utilization of these materials to model vegetative debris is consistent with the model scaling factor and with considerations to roughness characteristics.

The Group III flume runs determine the sediment loading and unloading rates of the two split dams. In the Phase I study, only the rectangular

Plate 19. Loading and unloading rate experiment -- top view of rectangular dam during loading at about prototype 1400 cfs.

Plate 20. Loading and unloading rate experiment -- upstream view of rectangular dam during loading at about prototype 1400 cfs.

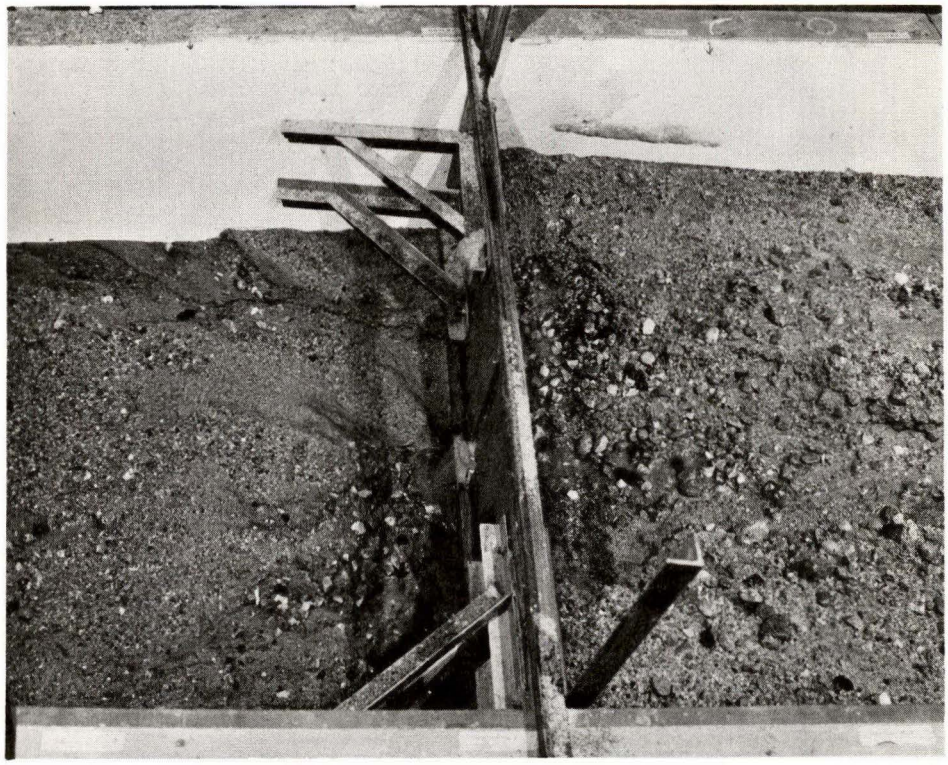


Plate 21. Loading and unloading rate experiment -- top view of rectangular dam post loading run.

Plate 22. Loading and unloading rate experiment -- upstream view rectangular dam post loading run.

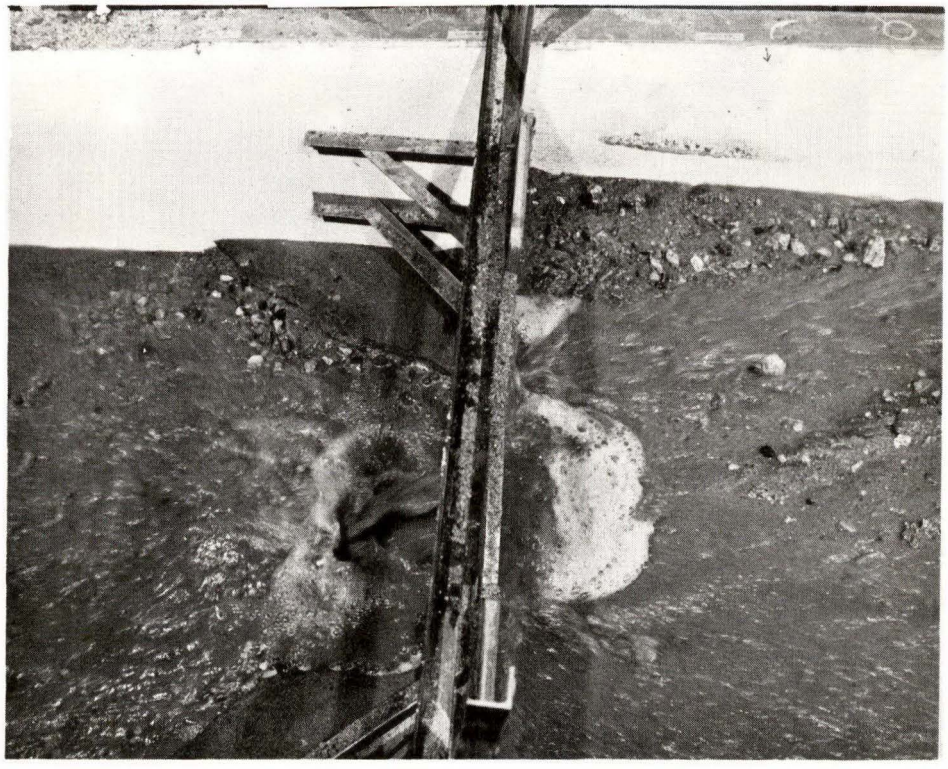


Plate 23. Loading and unloading rate experiment -- top view rectangular dam during unloading run.

Plate 24. Loading and unloading rate experiment -- downstream view rectangular dam during unloading run.

Plate 25. Loading and unloading rate experiment -- oblique upstream view rectangular dam post unloading run.

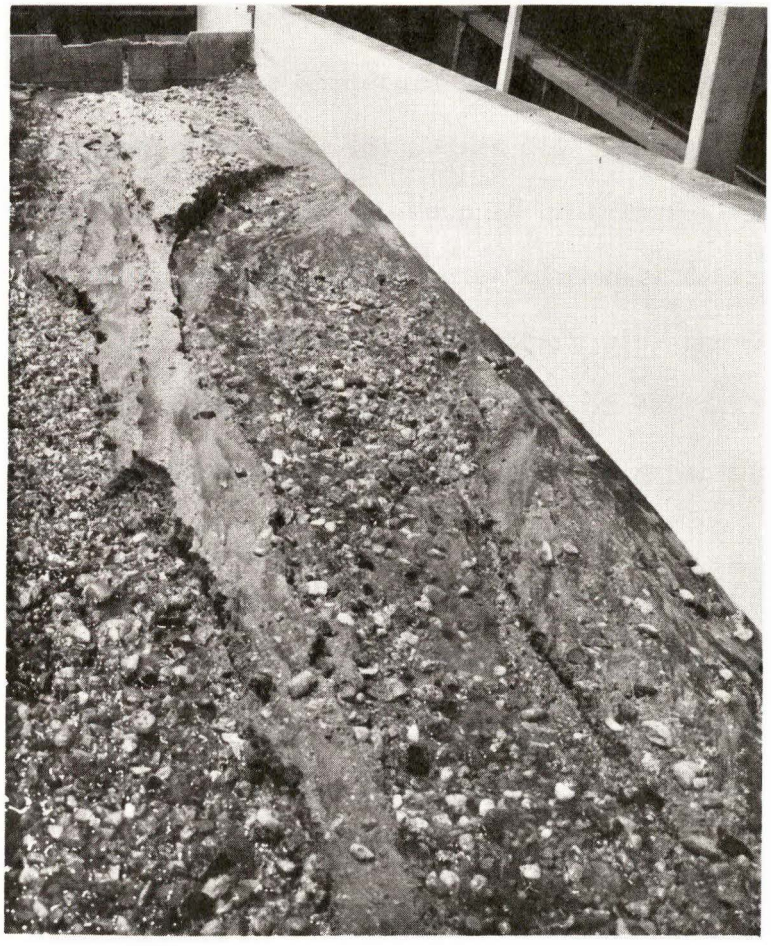


Plate 26. Loading and unloading rate experiment -- downstream view rectangular dam post unloading run.

structure and a 15 percent slope were considered. This group of runs is subdivided into three series: (a) Series I: maximum sediment supply is available throughout the run starting with an empty model using the sediment transport capacities determined in Group II runs, (b) Series II: no sediment is added to the flume to evaluate the debris cleaning efficiency starting with the structure loaded with sediment for various low flows (less than 1700 cfs), (c) Series III: one-half of the debris transport capacities determined in Group II runs is fed into the flume to evaluate the debris cleaning efficiency with this debris supply condition. The flume runs in this series start with the loaded structure. In these runs a six (6) inch layer of sediment was laid on the rigid flume bed and approximately 0.5 percent vegetative debris was added.

Plate 19 shows the top view of the loading runs (starting with no stored sediment upstream of the model dam) for water discharge of about 1400 cfs. Plate 19 shows the trapping of sediment behind the model dam and a large scour hole immediately below the split dam port. Plate 23 demonstrates the top view of the unloading runs (starting with sediment stored behind the model dam) for a water discharge of about 700 cfs and no debris supplied to the flume. This plate shows the self-cleaning feature of the split dam. Plate 23 illustrates the forming of an alluvial fan downstream of the structure during the unloading phase. Movies were taken of both the loading and unloading runs. Initial results of the Group III flume runs for the one shape and one slope are tabulated in Table 4. The determined loading and unloading rates are plotted in Figure 7. The loading rate of Series I runs can reach zero but cannot be negative because deposition will

Table 4. Group III runs--loading and unloading for different discharges and sediment supply rates (prototype units, rectangular shape).

Run*	Qw, cfs	$\frac{\Delta s}{\Delta t}$ ft^3/sec
F-1	2406	741
F-2	378	38
F-3	972	228
F-4	400	78
F-5	1684	500
S-1	188	-13
S-2	416	-25
S-3	972	-72
S-4	381	-47
S-5p	688	-16
S-6	688	-59
S-7p	856	-109
S-8p	1222	- 9
S-9	1684	-97

*F--loading run, S--unloading run, p--partial supply (1/2 supply).
Δs--sediment volume flowing into structure, minus sediment volume passing through hole in the model.
Δt--time interval for a given run.

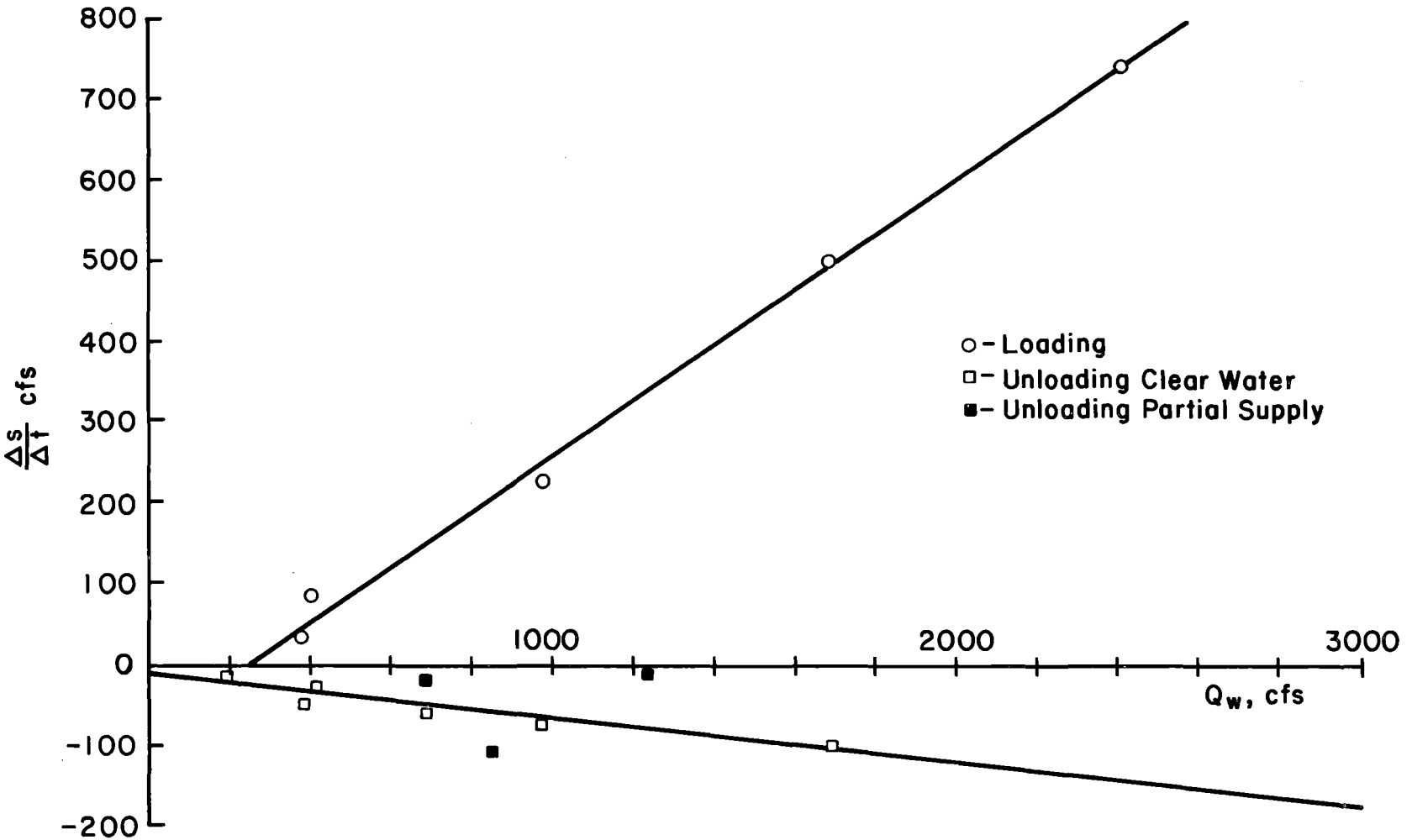


Figure 7. Loading and unloading rates vs. water discharge (prototype units).

always equal or exceed erosion of the prism at low flows and maximum sediment debris availability.

Initial results of the Group III runs indicate that the split dam can effectively store sediment during high flows and gradually empty during low flows that transport little debris. Figure 7 shows that unloading (scouring) rates are much smaller than loading (filling) rates. However, during a year a channel may experience a majority of low flows, thus, the total amount of sediment removed by low flow events can be large. The function of the split dam is to store debris during large runoff events and to gradually discharge the accumulated sediment during low flows. From the initial runs, it is concluded the split dam has desirable self-cleaning features. However, self-cleaning efficiency of the split dam is dependent on the distribution of low flows and their sediment loads. If nonflooding flow is not too small and if water is essentially clear, the self-cleaning efficiencies of the model dam is good. More flume runs are needed to determine the self-cleaning efficiency of the proposed structures over a wide range of possible flow conditions.

IV. RECOMMENDATIONS FOR PHASE II STUDY

Based on the Phase I study, the following scope of work is recommended for Phase II:

1. Continue with flume runs in Group III, Series 1 and 2, for slopes and model shapes other than that of Phase I. This will consist of approximately 30 runs.

2. Determine sediment loading rates for the top-tie pile wall dam, each on three slopes and document with photographs. Performance of this dam will be compared with the two split dams. This will require approximately six runs.

3. Determine the self-cleaning efficiency of the two prototype split dam shapes utilizing the fixed bed for a range of low flows with related sediment debris loads. These runs are equivalent to those of Group III, Series 3. The fixed bed will make it possible to control the sediment load carried by the flow from upstream. This work will consist of about 30 flume runs.

4. Develop a mathematical model that predicts hydraulic response of a proposed structure for different conditions, such as water and sediment hydrographs, structure and hole dimensions. This mathematical model will be developed considering the physical processes and the data obtained from the physical model study (Groups I, II and III).

5. Verify the mathematical model by comparing the predicted results with the measured data from additional flume runs utilizing a new structure shape. This will require appoximately 15 runs.

6. Determine the probability of plugging due to vegetative debris for the three split dam shapes and various clear water discharges. Thethird split dam would be the new structure shape to be used for

verifying the mathematical model. This will consist of about 27 runs.

7. Examine the self-cleaning efficiency of a selected split dam shape using preassigned water and sediment discharge and runoff duration representing characteristics of a small but typical watershed in the Angeles National Forest. If the financial condition allows, effects of combinations of water and sediment hydrographs on sediment movement and the self-cleaning efficiencies of the split dams should be studied. This will require a minimum of two combination runs.

Again, we can write

$$T_c = T_c(x) \tag{c.10}$$

and we can rewrite eqn. c.4

$$\frac{dG}{dx} = \left(D_c(x)\right)\left(1 - \frac{G}{T_c(x)}\right) \tag{c.11}$$

Rearranging,

$$\frac{dG}{dx} + G\frac{D_c(x)}{T_c(x)} = D_c(x) \tag{c.12}$$

Equation c.12 is in the form of a linear differential equation which can be solved using an integrating factor, of the form

$$e^{\int \frac{D_c(x)}{T_c(x)} dx}$$

and we find that the steady state sediment load per unit width at the bottom of a uniform slope of length, L, is

$$G(L) = e^{-\int_0^L \frac{D_c(x)}{T_c(x)} dx} \left[\int_0^L e^{\int_0^L \frac{D_c(x)}{T_c(x)} dx} \frac{D_c(x)}{T_c(x)} dx + c \right] \tag{c.13}$$

Which can be solved to any tolerance using numerical integration.

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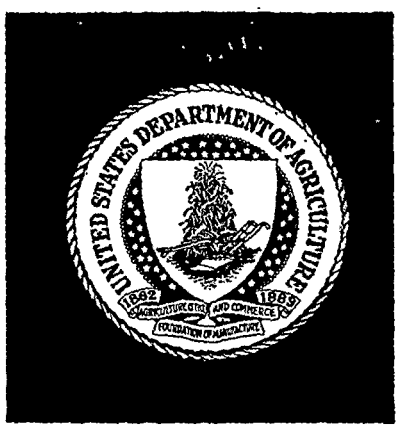

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